Amnesia and Future Thinking: Exploring the Role of Memory in the Quantity and Quality of Episodic Future Thoughts.

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Abstract

Objectives To examine the impact of memory accessibility on episodic future thinking.

Design Single case study of neurological patient HCM and an age-matched comparison group of neurologically healthy controls.

Methods We administered a full battery of tests assessing general intelligence, memory and executive functioning. To assess autobiographical memory, the Autobiographical Memory Interview (Kopelman, Wilson & Baddeley, 1990) was administered. The Past Episodic and Future Episodic sections of Dalla Barba's Confabulation Battery (Dalla Barba, 1993) and a specifically tailored Mental Time Travel Questionnaire were administered to assess future thinking in HCM and age-matched controls.

Results HCM presented with a deficit in forming new memories (anterograde amnesia) and recalling events from before the onset of neurological impairment (retrograde amnesia). HCM's autobiographical memory impairments are characterised by a paucity of memories from recent life. In comparison with controls, two features of his future thoughts are apparent: Reduced episodic future thinking and outdated content of his episodic future thoughts.

Conclusions This paper suggests we should look beyond popular conceptualisations of the past-future relation in amnesia via focussing on *reduced* future thinking. Investigating both the quantity and quality of future thoughts produced by amnesic patients may lead to developments in understanding the complex nature of future thinking disorders resulting from memory impairments.

Practitioner Points

- We highlight the clinical importance of examining the content of future thoughts in amnesic patients, rather than only its quantitative reduction.
- We propose an explanation of how quantitative and qualitative aspects of future thinking could be affected by amnesia. This could provide a useful approach to understand clinical cases of impaired prospection.

Limitations

- Systematic group investigations are required to fully examine our hypothesis.
- Although the current study utilised typical future thinking measures, these may be limited and we highlight the need to develop clinically-relevant measures of prospection.

Amnesia and Future Thinking: Exploring the Role of Memory in the Quantity and Quality of Episodic Future Thoughts

Throughout our waking lives, we ponder our future at least as frequently as remembering our past (D'Argembeau, Renaud & Van der Linden, 2011). Research from neuroimaging has demonstrated that in addition to its recognised role in remembering specific events from one's past (i.e., *episodic recollection*), the episodic memory system also underlies the ability to imagine events that may come to pass (i.e., *episodic future thinking*; see Schacter, Addis, Hassabis et al., 2012 for a detailed review). As Schacter & Addis (2009) propose under the *constructive episodic simulation hypothesis*, "episodic memory supports the construction of future events by extracting and recombining stored information into a simulation of a novel event" (p.1246). Hence, past remembering and episodic future thinking are seen as two sides of the same coin and share many characteristics: amongst other things, both involve the self, scene construction and vivid imagery (Rathbone, Conway & Moulin, 2011; Hassabis & Maguire, 2007; D'Argembeau & Van der Linden, 2006). For these reasons, and others, both are often described using the general term; *mental time travel* (Wheeler, Stuss & Tulving, 1997). One key difference however is that episodic recollection can be verified whereas episodic future thoughts vary on the degree to which the simulation maps onto one's expected future. Here, we define episodic future thinking as the construction of a personally plausible future event (see Cole, Fotopoulou, Oddy & Moulin, 2014) following common definitions employed in experimental work (Addis, Wong & Schacter, 2007; D'Argembeau & Van der Linden, 2004).

If the 'building blocks' of episodic future thoughts are episodic memories, then amnesics, with limited or complete loss of accessible episodic memories, should be severely deficient when attempting to describe the future. This is exactly what has been found in the foregoing literature. In fact, the crucial role of memory in episodic future thinking has never been more clearly illustrated than by the reduction in the detail and spatial coherence of future thinking (Hassabis, Kumaran, Vann & Maguire, 2007) or complete absence of future thinking (e.g., KC, Tulving, 1985, see also Rosenbaum et al., 2005) found in dense amnesic patients.

Until now, studies of amnesia have mostly examined episodic future thinking using methods that quantify aspects of future thoughts such as spatial coherence and amount of episodic detail (Hassabis, et al., 2007; Race, Keane & Verfaellie, 2011) or the quantity of episodic future thoughts themselves (e.g., Andelman, Hoofien, Goldberg, Aizenstein, & Neufeld, 2010), possibly because research questions concern the involvement (or not) of episodic memory in future simulation. Typically, a significant reduction of episodic future thinking in amnesics, compared to age-matched non-brain-damaged controls has been found in almost all published studies (Andelman et al., 2010; Hassabis, et al., 2007; Klein, Loftus & Kihlstrom, 2002; Race et al., 2011; Tulving, 1985; although see Squire et al., 2010 and Discussion). A similar approach has been employed to study the past-future link in dementia (e.g., Addis, Sacchetti, Ally et al., 2009; Gamboz et al., 2010) with largely concordant findings. This, along with research from imaging neuroscience and cognitive psychology, has shown that one necessary cognitive function for episodic future thinking is a psychologically and neurologically unimpaired episodic memory system (see Schacter et al., 2012 for a review). This assertion lies at the heart of recent theories of episodic memory and future thinking; particularly the *constructive episodic simulation* hypothesis (Schacter & Addis, 2007).

In their commentary of Suddendorf & Corballis' (2007) influential article, Tulving and Kim (2007), outlined two important dimensions of episodic future thinking; the neuropsychological capacity to engage in episodic future thinking (the *medium*), and the 'mental activity' that denotes its cognitive expression (the *message*). However, the application of this taxonomy has been left wanting; especially in Neuropsychology. The extant research on amnesia and mental time travel has focussed on deficits in the *medium* (i.e., negative symptoms represented by fewer responses on questionnaires measuring the underlying capacity of mental time travel) rather than analysing its qualitative nature, or *message* (i.e., positive symptoms represented by the meaning/content of each response).

An exception to this general emphasis on the *medium* is the recent interest in the linguistic characteristics of the content of episodic past and future thought produced by amnesics. Specifically, these studies investigated the interactive discourse (McKinley, McVittie & Della Salla, 2010) and narrative (Race, Keane & Verfaellie, 2015) characteristics of past and future thoughts. These studies diverge from traditional analysis of the *medium*, and examined hitherto unknown linguistic aspects of mental time travel, and similar to this paper, examine the meaning evident in episodic future thought narratives. The aim of the present study, however, was not to understand the impact of researcher-patient discourse (McKinley et al., 2010) or narrative characteristics *per se* (Race et al., 2015), but to attempt to investigate if and to what extent memory inaccessibility can affect the manifest content of episodic future thought.

Herein we argue that the examination of the *medium* of mental time travel in amnesia is too restrictive, focussing exclusively on prescribed failings of prospection, answering specific theoretical questions, but potentially missing other theoretically and clinically relevant issues. An implication of the *constructive episodic simulation* hypothesis is that the ‘islands of memories’ which *are* available in amnesia will be drawn upon as the building blocks of episodic future thoughts. However, the emphasis on the *medium* of episodic future thinking means that this possibility remains underexplored.

It is typical that instead of resulting in complete episodic memory loss, amnesia involves memory loss which extends temporally before the onset of the amnesia by months, years or decades (Kopelman, 2002). This is termed *retrograde amnesia* (RA) and accompanies the more characteristic type of amnesia observed following neurological injury, the inability to form new memories after the onset of amnesia, termed *anterograde amnesia* (AA), commonly resulting in a limited pool of distant memories available in amnesia.

If memories are the 'building blocks' of future events, the type and amount of memories available to amnesic individuals will determine the amount and content of their episodic future thoughts. Patients with AA and 'islands' of unimpaired access to remote memories (see Medved & Hirst, 2010) may provide informative data because they can highlight the importance of how accessible memories can be drawn upon in episodic future thinking. In these particular patients, we would expect that episodic future thoughts would lack relevance to ongoing goals, providing an outdated view of "now" and the future (Conway, Loveday & Cole, 2015). Importantly, episodic future thinking, which arguably underlies and influences goal-directed cognition (Cole & Berntsen, 2015; Suddendorf & Corballis, 2007; Szpunar, Spreng & Schacter, 2014) may lose its adaptiveness and become currently irrelevant and maladaptive. For example, a retired patient may simulate a future scenario from mnemonic details extracted from when they were a city banker several decades ago. Specifically, without a healthy functioning episodic memory system, we predicted that the *personal plausibility* of episodic future thoughts (and their relevance to current reality) would be significantly reduced. To this end, we assessed the quantity *and* qualities of episodic future thoughts in a patient with amnesia and compared his responses to those of age-matched neurologically healthy controls. We present patient HCM, who presented with AA and temporally graded RA.

HCM

We report HCM's neuropsychological test scores from 2013 (Table 1) and a neuroradiological scan from 2008 (Figure 1). Testing of his autobiographical memory, confabulation and mental time travel abilities took place in 2011. This project obtained approval from the UK National Research Ethics Service committee and Neurorehabilitation Centre.

Biographical Information

HCM is a 66 year old male. He attended primary school (5-12 years), and successfully gained access to the higher level of secondary schooling (Grammar School) by passing entry examinations at 11 years. In accordance with his secondary schooling, HCM passed 11/13 Ordinary Level General Certificate of Education (GCE) Examinations. He achieved a higher educational qualification in Electrical Engineering at a college whilst working at the postal service. He also completed a degree and studied toward a doctorate (only first year completed). In terms of familial relationships, he married in the UK, fathered four children and moved to Germany. He is now separated from his wife and lives under the 24-hour care at a neuropsychological rehabilitation centre in the north of England. His children visit him regularly.

Medical History

HCM has a history of neurological damage resulting from several cerebrovascular injuries. Earliest evidence of such an injury was a cardiovascular accident in 1998 (at 51 years old). This resulted in a left lateralised haemorrhage which required a craniotomy to alleviate pressure. He also sustained two traumatic head injuries, one in 2000 (at 53 years) when he was assaulted with a blow to the head and one in 2002 (at 55) when he fell down a staircase. After being hospitalised, he was admitted to a specialist neurobehavioural assessment and post-acute rehabilitation centre for people with acquired brain injury to remediate ongoing cognitive, behavioural and physical deficits.

Based on clinical notes and a neuroradiologist assessment of a structural MRI brain scan from 2008 (see Figure 1), there was evidence of small vessel change, micro-infarcts in subcortical areas (e.g., cerebellum and basal ganglia) and enlarged ventricles (around 50% larger than healthy controls based on the Neuroradiologist's assessment). Although many of these micro-infarcts would have been asymptomatic, it is probable that HCM suffered a transient ischemic attack in 2010 evidenced by a CT scan. Although potentially germane to his memory difficulties, identification of damage to the hippocampal complex was unfeasible due to the section (axial and sagittal views included; no coronal view available) and resolution of the available MRI scan. The general neurological picture was of multiple diffusely spread infarcts indicative of global atrophy extending to both cortical and subcortical regions. His medication largely addressed his mood and physical problems[1].

Neuropsychological Profile

HCM was tested by two trainee Clinical Psychologists. Although HCM agreed to participate and was enthusiastic about participating (in both Neuropsychological Tests and Experimental Measures), he required 11 testing sessions to complete a battery of varied psychometric testing (see Table 1). This was due to HCM repeatedly stopping testing when he became aware of his inability to complete tasks to pre-injury levels. This suggests that although he had online awareness of his reduced abilities, this did not augment his global self-knowledge of his current abilities (see Toglia & Kirk, 2000).

General Cognitive Function. By administering the TOPF-UK (Wechsler, 2011), an estimate of pre-morbid cognitive function can be determined. HCM scored within normative range on all sections of this test (see Table 1). He also completed the Wechsler Adult Intelligence Scale IV (WAIS-IV, Wechsler, 2008), covering four indices of current cognitive function. Scores on the TOPF-UK and WAIS-IV have a mean of 100 and standard deviation of 15. When compared with his current cognitive abilities (WAIS-IV scores), scores on TOPF-UK showed that working memory, perceptual reasoning and processing speed were most affected by his neurological injuries (scores = 55, 63, 50 versus 106, 104, 101, respectively). His working memory deficit is illustrated by his poor performance on digit span and mental arithmetic tasks (scores = 3 and 1, respectively). His poor performance on perceptual reasoning and processing speed index may also be due to fundamental working memory deficits, as the subtests he had most difficulty with required manipulation and storage of information (e.g. visual puzzles on the Perceptual Reasoning Index). In contrast, his linguistic abilities were a perpetual strength of his cognitive profile and remained within the normal range.

HCM's orientation was examined using a subsection of the Confabulation Battery which assesses orientation in time and place (Dalla Barba, 1993). This showed that HCM had difficulty in estimating current temporal information and was unable to provide an answer concerning the current day, date or month (see Table 3). Also, HCM was unable to recall when he was admitted to the rehabilitation unit. His current year estimate predated the current year by a decade. Knowledge of current location was more accurate: HCM accurately described the country, city, and building ('hospital building') indicating that he did not have global unawareness of his current situation.

Memory. The Wechsler Memory Scale IV (WMS-IV; Wechsler, 2009) assesses different domains including working, visual and verbal memory. HCM performed particularly poorly on tests involving visual information and delayed recall compared with the estimated population mean of 100 (see Table 1). These difficulties were compounded when HCM was asked to replicate any of the pictures he was presented with; immediately or after a 25-30 minute delay. Actually, on all tests involving a delay between study and test, HCM scored at floor level, saying that he was not able to remember anything the clinician referred to in these tasks (e.g., visual reproduction II & logical memory II, standard scores, both = 1). His verbal immediate memory was the least impaired, and HCM was able to recall portions of a story just previously read aloud (logical memory I, standard score = 9). However, despite these moderate-at-best abilities, HCM was unable to retain information over short durations regardless of modality. This, and the fact that he was unable to remember meeting the first author, who met him three weeks previously, underlines HCM's anterograde amnesia.

Executive Function. Five tests from a standardised battery of executive function (Delis-Kaplan Executive Function System, Delis, Kaplan & Kramer, 2001) were administered. See Table 1 for scores (Mean=10, Standard deviation=3). HCM was very competent at reasoning, evidenced by scoring above average on the 20 questions test in which the most effective yes/no questions should be self-generated in order to obtain the identity of an object from a visually presented array (standard score = 14). HCM's principal executive deficit was in the domain of cognitive switching (verbal fluency, standard score = 2). Therefore, HCM presented with executive dysfunction restricted to abstract thinking (see Proverbs test, standard score =7) and switching in the context of spared reasoning abilities.

Experimental Measures

Method

Materials

Three questionnaires were administered to HCM to determine the extent of episodic and semantic autobiographical memory disturbances, subjective temporal experience and mental time travel abilities. These were the *Autobiographical Memory Interview (AMI; Kopelman, Wilson & Baddeley, 1990), Confabulation Battery (Dalla Barba, 1993) and Mental Time Travel Questionnaire*, respectively. To provide a comparison for HCM's responses, a case-control design was employed whereby three healthy participants of a similar age (Range, 61-67, one male), with no history of brain injury, were administered the same Questionnaires (with a shortened version of the Confabulation Battery). For accuracy verification purposes, a copy of each participant's responses was sent to a close relative. Memories were rated for whether they happened as described and future events were judged for likelihood of occurring to that individual (1-5 scale, cf. personal plausibility, see Scoboria et al., 2004). Employing confederate ratings represents a methodologically rigorous aspect to this study that is not commonly adopted in studies of future thinking. Where appropriate, Crawford & Garthwaite's (2002) t-test and Crawford, Garthwait and Porter's (2010) effect size estimates (z_{cc}) were computed which are tests designed for comparing single cases with a small control group.

Autobiographical Memory Interview. To assess HCM's knowledge of his childhood, early adulthood and recent life, the AMI (Kopelman, Wilson & Baddeley, 1990) was administered. This test assesses knowledge of incidents and personal semantics across life periods, with greater scores granted for detailed responses, which are compared to the range of scores expected in the healthy population (using the AMI manual). In addition, the specificity of autobiographical incidents reported by HCM and age-matched controls were compared on a measure of episodic *specificity*; the qualitative 0-3 scale used in Kopelman et al. (1990). Using this scale, a response based on semantics or no response is rated 0, a vague personal memory is rated 1, a moderately specific event (personal but non-specific or specific without time and place detail) is rated 2, and a full episodic memory specific in time and place is rated 3.

Subjective Temporal Experience. The full Dalla Barba Confabulation Battery (Dalla Barba, 1993) was administered as it included past and future episodic questions, an orientation section, and two sections probing public and personal semantic information (Dalla

Barba, Cappelletti, Signorini & Denes, 1997) [2]. No additional prompts were provided. Healthy Controls were only administered Past and Future Episodic Sections.

All responses were transcribed and coded according to Dalla Barba's criteria (e.g., all responses except "don't know" were classified as confabulations in *Don't Know* sections). Confabulations were determined by consulting rehabilitation staff and HCM's son. Although past events can be classified as confabulatory if they are grossly inaccurate, future confabulations may appear difficult to assess as there is no experienced event for comparison. However, future confabulations can be conceived as personally plausible or implausible (by individuals aware of his/her probable future), hence 'future confabulations' were determined via a scale of personal plausibility (also see Cole et al., 2014; Dalla Barba et al., 1997 & Klein et al., 2002 for related discussions). If confederate ratings indicated unlikely events (1 or 2, on a 1-5 scale of occurrence probability for the tested individual, 1=not at all likely, 5 =extremely likely), they were classed as confabulatory unless inaccuracies were minor. Finally, the amount of accurate and omitted responses was also recorded. In this way, *distortions*, *accuracy* and *omissions* in all sections were assessed.

Mental Time Travel Questionnaire. A further Mental Time Travel Questionnaire was administered, which assessed episodic past then episodic future thinking at three temporal distances from the present (one week, 6-12 months, 5-10 years, presented sequentially). Participants were instructed to remember a specific past event or imagine a specific future event that will take place in each temporal period. A maximum of two experimenter prompts were provided (e.g., can you remember a specific event?), and they were rated on specificity using the AMI scale (Kopelman, Wilson & Baddeley, 1990) which was easily adapted to classify past and future events[3].

To clarify, whereas the AMI covers temporal periods of one's recent life (past 5 years), early adulthood and childhood, the past and future periods covered by the other two questionnaires extend to temporally near events (Confabulation Battery) and up to ten years into the past/future (Mental Time Travel Questionnaire).

Results

Autobiographical Memory Interview

The results displayed in Table 2 show HCM's scores and the range expected in healthy individuals (from AMI Manual). For questions probing personal semantics, HCM was able to remember a variety of facts from childhood (ages 4-16 years). Specifically, he was able to name school friends, schools, and a college he attended from that period. However, his responses fell below the normative range for Early Adulthood (for example, he could not remember the date or place of his marriage) and there was a paucity of information for Recent Life: He was unable to name any of the staff at the rehabilitation centre or where he was last Christmas (three months prior to testing).

In terms of episodic remembering, HCM was able to recall specific events from Childhood, within the normal range and similar to that of age-matched controls (see Table 2). For instance, HCM vividly described a school Rugby trip, including specific details such as how he washed. His episodic recall from Early Adulthood was somewhat impaired, falling below the normative range (but not significantly different from controls). This period of recalled events covers periods from HCM's College life (age 16+) until the birth of his first child (age 31). As HCM's first stroke was in 1998, his limitations recalling events from this period are likely due to retrograde memory deficits. HCM also had clear deficits in recalling any event from Recent Life (previous 5 years) - far below the lower bound of healthy individuals and age-matched controls (see Table 2). Of three opportunities, the only verified recent event HCM described within Recent Life was a description of general scenarios which occur regularly at the rehabilitation centre (see Appendix)[4].

HCM's son verified the majority of HCM's responses. Only minor errors and inaccuracies were noted, indicating deficient memory, rather than confabulation, and therefore RA for the Early Adulthood period. In contrast, the onset of his neurological impairments occurring between 51 - 55 years of age, indicates an AA cause for his impairments in memory for Recent Life.

The Dalla Barba Confabulation Battery

The complete scores (correct, confabulatory, incorrect or "don't know") on all subcategories of the Battery are presented in Table 3. In terms of knowledge of public events (General Semantic section), HCM was unable to name the current Prime Minister but retained good knowledge of many temporally distant public happenings which were probably well-learnt facts (e.g. When did World War II start? What happened to President Kennedy?).

Importantly, regarding his answers on the Past Episodic section, HCM's responses were characterised by errors of omission, responding with "don't know" for 8/10 questions (in comparison, age-matched controls produced 0/10 "don't know" responses). Additionally, HCM produced significantly fewer correct responses than healthy controls ($t(2)= 6.93$, $p < .05$, two-tailed, $z_{cc} = -8$), and his responses were vague and general.

In the Future Episodic section, HCM responded "don't know" to 4/10 questions which happened on zero questions in heathy age-matched controls. HCM was unable to imagine *any* temporally and spatially specific future event probed throughout this questionnaire. Of HCM's future thoughts, two were judged unlikely to happen by his son. For instance, spending next Christmas with family and going to talk to somebody about his daily plans (likelihood ratings for both = 2, on a 1-5 scale). Of his two other future event responses, one was judged on the mid-point of the likelihood scale (*a trip to the restaurant*, likelihood rating = 3) and the other was rated somewhat likely by his son (*a possible holiday abroad*, likelihood rating = 4). Overall, compared to healthy controls, HCM's imagined future events were judged as less likely to transpire (Healthy Controls, $M = 4.67$, $SD = 0.35$; $t(2) = 5.37$, $p < .05$, two-tailed, $z_{cc} = -6.20$). We present a representative excerpt from HCM's responses and those of healthy controls in the Appendix, including ratings of likelihood.

Mental Time Travel Questionnaire

In the Memory section of this task, HCM's first response to all cues was that he was unable to remember anything, and prompting twice for specific events for each temporal cue aided the retrieval of only two memories that were not specific (both were personal memories without reference to time *and* place). Both were partially accurate according to HCM's son. Hence, HCM produced no specific personal memories. This was in stark contrast to matched controls who, on average, produced a high percentage (89%) of specific memories and overall 94% were verified as wholly accurate by confederates. Healthy controls also required fewer prompts than HCM to generate specific memories ($M = 0.33$, $SD = 0.58$ versus HCM = 2 per memory).

For the Future section, HCM gave responses to 2/3 future cues, which were both temporally distant (6-12 months, 5-10 years), and rated as highly implausible by his son and rehabilitation staff (likelihood = 2, both). HCM's future thoughts were both classed as non-specific personal events, whereas the majority (67%) of controls' future thoughts, on average, were classed as specific. Also, these future scenarios were significantly less likely to occur than those produced by healthy controls (Controls, $M = 4.6$, $SD = 0.23$, $t(2)= 9.79$, $p < .01$, two-tailed, $z_{cc} = -11.30$). Illustrating the improbability of these events, HCM stated that he would invite his family to his apartment. In fact, he owns a local apartment but is no longer able to access this due to mobility problems. Clinical staff confirmed he had not resided at his apartment since admission and was not expected to live there in the future. Nevertheless, HCM voluntarily imagined a scenario involving his apartment. In a similar vein, in 5-10 years he envisioned 'passing' a variety of clinical examinations and moving into his apartment. Both of these events would be unlikely to occur to HCM (i.e., they would be personally implausible, see Cole et al., 2014), according to clinicians and his son, suggesting that his future thoughts were outdated.

Discussion

In this paper, we aimed to highlight how amnesia can affect the quantity and quality of future thinking following the distinction between the *medium* and *message* of mental time travel used by Tulving and Kim (2007). To investigate this, we assessed a patient with neurological damage, HCM, who had an extended period of anterograde memory deficits, and temporally graded retrograde amnesia. In contrast to his memory disorder and other more moderate cognitive deficits (e.g., some specific executive deficits, see Neuropsychological Profile), his comprehension and linguistic abilities were unimpaired. By investigating HCM's past and future thinking using a neuropsychological approach, we replicated a robust finding from prior studies of amnesic patients demonstrating a severely reduced episodic future thinking ability (see Schacter et al., 2012), which largely mirrored HCM's deficit in past remembering (e.g., when asked what he did yesterday, he replied "can't remember at all", see Appendix). In addition, and for the first time, we demonstrated how the unavailability of recent semantic and episodic autobiographical knowledge but availability of distant semantic and episodic autobiographical knowledge can fundamentally affect the content of future thoughts. Specifically, HCM incorporated outdated autobiographical knowledge to describe his self-perceived future: HCM's future thoughts were judged as grossly implausible within the context of his current cognitive and physical capabilities. Although this case investigation requires replication in groups studies of neurological patients (see 'Methodological Limitations' below), the novelty and value of this study is to highlight the relation between memory impairment and the (outdated) content of future thoughts.

In general, HCM's descriptions of his personal past and future can be characterised by a reduction of episodic information (similar to the 'blankness' of the subjective past and future experienced by patient KC, as reported by Tulving, 1985). HCM's first response to almost all past cues on the Mental Time Travel Questionnaire and Dalla Barba's Confabulation Battery was that he was unable to remember anything and he has profound difficulties generating specific upcoming events (indicating a reduced *medium*, see also patient MC, Andelman et al., 2010). Furthermore, in the Future Episodic section of the Confabulation Battery, most responses that were not 'don't know' responses were judged as personally implausible. Also, in the Mental Time Travel questionnaire, HCM generated personally implausible imagined future scenarios in this way, indicating a distorted *message* (although there are clearly several dimensions on which the content of episodic future thinking potentially varies, e.g., emotional positivity). Notably, none of HCM's future scenarios described his ongoing difficulties arising from his neurological impairments, or attempts to remediate them within rehabilitation: Activities that would have occurred frequently during the past decade. This pattern of results indicates that the content of future thought is inherently linked to accessibility of autobiographical memories. This data also indicates that HCM's distant semantic personal facts were more available than recent semantics, as suggested by his AMI responses. Indeed, recent data from patients with dementia indicates that semantic memory may have an important role in generating plausible episodic future thoughts (see *semantic scaffolding hypothesis*, Irish, Addis, Hodges & Piguet, 2012).

Importantly, the ability to remember the past and imagine the future is argued to contribute to our sense of a temporally extended self (Klein et al., 2002; Prebble, Addis & Tippett, 2013) This extended "now" may be especially relevant for tracking personal goals (see Cole & Berntsen, 2015; and Conway, Loveday & Cole, under review, for a theoretical examination). Considering this, and the proposed functional role of future thinking in anticipation and planning (Klein et al., 2002; Suddendorf & Corballis, 2007), we propose a broader investigative approach to mental time travel in individuals with memory deficits, rather than studies limited to examining the impact of memory disorders on only its retrospective component.

In terms of a possible explanation of HCM's pattern of reduced quantity (i.e., *medium*) and the distorted quality (i.e., *message*) of future thinking, we presume that encoding and consolidating ongoing experience updates the autobiographical memory base (where self and memory information intersect within different levels of abstraction, from specific episodes to more abstract knowledge such as self-images, lifetime periods and general events, see Conway & Pleydell-Pearce, 2000; Conway, 2005). Thus, a lack of updating will affect the self and memory, especially the relation between episodic memories and the self (see Rathbone et al., 2009; although stable aspects of memory and the self, established before neurological injury, may be relatively unaffected, see Prebble, Addis & Tippett, 2013 for a comprehensive review and theoretical framework). Episodic memories may be especially important for the self as, in contrast to semantic memory, it has an inherent sense that one is re-experiencing an event in the present moment (Tulving, 1985; Prebble et al., 2013). In addition, we argue that a lack of updating can also cause personally implausible future thoughts (as was observed in HCM, but not controls) inasmuch as confidently believed future thoughts could be based on accessible but outdated mnemonic elements (see Conway, Loveday & Cole, 2015 for a more thorough treatment). In short, episodic future thinking could be highly *constrained* by one's *current* autobiographical memory, which itself determines self-perceptions, memory retrieval and shapes current goal structures (Conway, 2005): Episodic future thoughts of a final year university student will likely be very different from her episodic future thoughts as a high-school student because, amongst other factors, new autobiographical memories from the university period will shape, and limit, new goals and episodic future thoughts.

We argue that – without neurological damage - HCM might have described personally plausible future scenarios drawing upon recent events (as did the age-matched controls). Instead, with AA and temporally graded RA, he described future events with relevance to previous lifetime periods (e.g., owning an apartment) that are not relevant to current circumstances, and this could appear as confabulation-like behaviour (cf. Cole et al., 2014; Dalla Barba et al., 1997): Confabulation-like behaviour that, at some point in HCM's past, would have been relevant.

Another area worthy of discussion is awareness, which, as clinical professionals appreciate, is often compromised after brain injury. This is a critical issue in Neuropsychological Rehabilitation, as some patients are not aware of their deficits and the restrictions that these may impose on their present (and future) life (Toglia & Kirk, 2000). It is possible that self-awareness may be associated with the content of personally implausible episodic future thoughts. In neuropsychological models of awareness, a distinction is made between self-knowledge (knowledge one brings to each task) and on-line awareness (i.e., self-monitoring and -regulation within a task, see Crosson et al., 1989; Toglia & Kirk, 2000). Indeed, it is postulated within a recent model (Toglia and Kirk, 2000) that in addition to other factors, previous self-knowledge (memories) may inform *expectancies* – a construct which may overlap, or be associated, with episodic future thinking (see Szpunar, Spreng & Schacter, 2014 for a relevant taxonomy of future-oriented cognition). The link between awareness and episodic future thinking in acquired brain injury is undoubtedly a complex issue. However, this investigation suggests that memory failure may not only lead to reduced and personally implausible future thoughts, but may also indicate wider self-awareness deficits.

Another factor related to personally implausible future events is self-enhancement. One possibility is that HCM created self-enhancing future events in order to escape the barriers to independence he experiences in daily life at the rehabilitation centre[5]. An unrealistic future could be 'motivated' toward a wished-for version of the self (Conway and Taachi, 1996, see also Fotopoulou, 2010). However, the extent to which HCM's apparent future positivity bias is due to memory disturbances or other cognitive disturbances (e.g., executive dysfunction, lack of self-awareness) is presently unclear.

Another question should also be considered: What was the potential consequence of executive impairments on HCM's past and future scenarios? A body of research now indicates that executive function, mediated by prefrontal regions, can effect autobiographical memory (Simons & Spiers, 2003). In particular, damage to prefrontal cortex typically affects cognitive control and monitoring of memory retrieval (Burgess & Shallice, 1996; Simons & Spiers). There is evidence from healthy (D'Argembeau, Ortoleva, Jumentier & Van der Linden,, 2010; Cole, Morrison & Conway, 2013) and brain-damaged individuals (Berryhill, Picasso, Arnold et al., 2010; de Vito, Gamboz, Brandimonte et al., 2012) that executive function also has a role in EFT. In a study of individuals with Parkinsons disease, patients produced future events with reduced episodic detail, especially when novel event constructions were required (de Vito et al., 2012). In cases with extensive PFC damage, the monitoring component of episodic future thinking becomes more transparent, as patients misperceive extremely implausible future events as personally plausible (patient MW, Cole et al., 2014). Currently, the limited amount of extant cognitive and neuropsychological research limits an accurate view on the role of executive function in episodic future thinking. In terms of HCM, his limited executive impairments (see Table 1) and lack of confabulations indicate that his major impairments were memory-related.

The principal aim of the current investigation was to examine the phenomenon of episodic future thoughts after compromised autobiographical memory accessibility, not to comprehensively distinguish between several explanations: This would require a larger pool of data. Future research will be necessary to clarify the extent to which the personally implausible content of amnesics' future thoughts is due to memory accessibility, awareness, executive function, self-enhancement or a combination of these (possibly interacting) factors.

Lastly, it is interesting to note that at first blush, the data from HCM appear to support the finding of one study demonstrating unimpaired *medium* of future thinking in neurological patients with damage to regions associated with declarative memory processes (Squire et al., 2010; but see Maguire & Hassabis, 2011). In particular, results from HCM appear to be similar to those from patient GP (with focal medial temporal lobe damage), who produced coherent episodic future thoughts despite impaired autobiographical memory from his recent life. Like here, it was argued that GP used his remote autobiographical memory to construct future scenarios (Squire et al., 2010). As opposed to Squire and colleagues though, our data agrees with the idea that episodic memory is *functionally necessary* (see Humphreys & Price, 2001) for future thinking because a reduced *medium* in past *and* future thinking was found in HCM (note that other patients in Squire et al did not exhibit severe deficits in autobiographical memory, see Maguire & Hassabis, 2011). On the whole, comparisons between this study and that of Squire et al (2010) should be made with caution because of differences in assessment tools and the neuropsychological profiles of the patients across studies.

Methodological Limitations

At this point, it is important to highlight some methodological limitations associated with neuropsychological investigations of this nature. Like almost all single case designs, our data is taken from post-injury assessment. Therefore, the precise change in memory capacity due to neurological damage is assessed by comparing premorbid estimations (here, TOPF-UK) and scores from an age-matched group of neurologically unimpaired individuals with the patient's post-injury performance. However, considering HCM's educational history and pre-morbid estimates, it is inferred that pre-morbidly he was intelligent and had at least normal cognitive abilities, and therefore the significant decline in memory function was due to neurological damage. Secondly, due to restrictions imposed by the questions of the AMI, the precise onset and gradient of RA is difficult to estimate. Yet, HCM presented with a clear degradation in autobiographical memories experienced before the onset of neurological impairment (i.e., at 51-55 years of age, see Results), in addition to clear AA-related deficits thereafter. Thirdly, we focus here on the effect of memory in future thinking and *subsequently tested* episodic and semantic aspects of his autobiographical knowledge (i.e., there was no objective measure of encoding). However, and notwithstanding the possible (but moderate) role of executive deficits in future thinking (e.g., deVito, Gamboz, Brandimonte et al., 2012, see discussion above), the case of HCM replicated the robust link between episodic memory and future thinking from the amnesia literature (Schacter et al., 2012 for a review).

Lastly, we acknowledge that group studies of patients with well-characterised acquired neurological damage who thereafter experience focal AA will be necessary. If our general explanation is correct, episodic future thoughts will be extracted and recombined from *available* autobiographical knowledge. Based on the constructive episodic simulation hypothesis (Schacter and Addis, 2007), both memories and episodic future thoughts should be outdated, pertaining to periods *preceding* memory impairment.

Implications for Neuropsychological Rehabilitation

It is presumed here that distorted and outdated episodic future thinking can have clinical implications for self-regulation, motivation and appropriate behaviour. Firstly, personalised and collaborative goal setting is becoming more prevalent for patients in

Neuropsychological Rehabilitation Centres (e.g., McMillan & Sparks, 1999). However, this case study highlights how personally implausible episodic future thoughts could disrupt or prevent effective rehabilitation goal setting and goal attainment (i.e., patients being less motivated to set goals that they cannot imagine). Also, it is an open question whether personally implausible episodic future thoughts that patients *can* envisage are related to the overestimation of current and expected functional skills typically found after neurological damage (Prigatano, 1996; cf. HCM's future thought concerning his apartment). Secondly, as previously alluded to, the link between self-awareness and episodic future thinking is an area which deserves empirical attention. Thirdly, in agreement with Andelman et al (2010), a fruitful research endeavour may be in formalizing reliable measurement of episodic future thinking in clinical patients, especially those with significant episodic memory difficulties. Presently, available questionnaires (e.g., Memory and Temporal Experience Questionnaire, Klein et al., 2002) are used principally for research purposes. However, more detailed work is required to establish the reliability of these measures in clinical populations, as well as the concurrent and predictive validity of related constructs (e.g., decision making, self-regulation). In this way, researchers can investigate the link between future thinking disorders and other clinically relevant cognitive and behavioural disorders.

Summary

The case of HCM highlights a novel aspect of prospection difficulties resulting from neurogenic memory problems. Specifically, we show that extended periods of AA, and temporally graded RA, can lead to an outdated autobiographical memory base which in turn results in highly implausible episodic future thoughts. The implications for this upon self-awareness and goal-setting should be a priority for future research.

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Footnotes

Footnote 1: Rispiridone, 1mg daily for mania, used as mood stabiliser; melatonin MR 2 mg daily for insomnia; Sodium Valproate 500mg 3 times daily for mood stabilisation;, Aspirin 75mgs once daily for prevention of cardio-vascular conditions; Simvastatin 40mgs once daily for raised cholesterol and Lansaprazole GR 30 mgs twice daily for lower intestinal tract inflammation.

Footnote 2: Past and future sections of the Confabulation Battery are identical to the 'lived past' and 'lived future' sections in Klein, Loftus & Kihlstrom (2002) Memory and Temporal Experience Questionnaire

Footnote 3: As an exploratory measure, we also asked participants to complete a set of phenomenological ratings for each of their past/future responses on the Mental Time Travel Task (these were; *vividness, emotional valence, emotional intensity, visual perspective*). However, although these data replicated robust past-future differences (e.g., the future positivity bias), no theoretically significant differences were identified between ratings of the healthy controls and patient HCM. Thus, to present the reader with the most meaningful results, these data are not presented here.

Footnote 4: To assess convergent validity, HCM and controls' responses to Autobiographical Incidents on the AMI were also coded according to the Levine et al. (2002) coding scheme. This showed a correspondence between this measure and the 0-3 scale of specificity used herein (r = .47, p < .005).

Footnote 5: We thank an anonymous reviewer for raising this possibility

Figure Captions

Figure 1. Axial section of patient HCM from a structural MRI scan (produced in 2008). This section illustrates the extent of his enlarged left ventricle, and small vessel change bilaterally (indicated by black arrows). Identification of damage to the hippocampus was unfeasible due to the sections (no coronal view) and the resolution of the above scan.

Table 1. HCM's Performance on Standardised Neuropsychology Measures

Measure	Score	Description
Pre-morbid IQ (TOPF-UK)		
Full Scale IQ	104	Average
Verbal Comprehension	103	Average
Perceptual Reasoning	104	Average
Working Memory	106	Average
Processing Speed	101	Average
General Cognitive Function (WAIS-IV)		
Verbal Comprehension	96	Average
Perceptual Reasoning	63	Extremely Low
Working Memory	55	Extremely Low
Processing Speed	50	Extremely Low
Anterograde Memory (WMS-IV)		
Auditory Memory	57	Extremely Low
Visual Memory	40	Extremely Low
Immediate Memory	63	Extremely Low
Delayed Memory	40	Extremely Low
Executive Function(DK-EFS)		
Category Switching (Correct)	3	Impaired
Category Switching (Accuracy)	2	Impaired
20 Questions Test	14	Above average
Word Context Test	9	Average
Proverb Test	7	Borderline impaired

Note: All tests were administered by clinical staff in 2013. Descriptions of performance on DK-EFS sub-tests were based on a 1 SD cut-off signifying impairment. Category Switching scores were both part of the Verbal Fluency tasks of the DK-EFS Battery. All scaled scores were age-corrected according to the relevant test manuals.

Table 2. HCM's pattern of Total Sematic and Episodic Scores on the AMI compared with Normative Scores (range in parentheses) and Healthy Controls.

	Personal Semantic	Autobiographical Incidents	
	HCM (Normative range)	HCM (Normative Range)	HC Mean (SD)
Childhood	18 (16-21)	8 (6-9)	7.67 (1.15)
Early Adulthood	12 (17-21)	6 (7-9)	7.67 (1.15)
Recent Life	2.5 (19-21)	1 (7-9)	8.67 (0.58)*
Cumulative Total	32.5 (54-63)	15 (19-27)	24 (2.65)$^{+}$

Note: HC = Healthy Controls. Normative scores taken from the AMI manual (Kopelman, Wilson & Baddeley, 1990). Significant differences ($p < .05$, *two-tailed*) between HCM and healthy controls, as analysed with Crawford & Garthwait (2002) single case statistics, are denoted by *. + represents a marginally significant difference ($p = .098$).

Table 3. HCM's Performance on the Confabulation Battery Compared with Healthy Controls (*percentages*)

	Correct		Incorrect		Confab.		Don't Know	
	HCM	*HC*	*HCM*	*HC*	*HCM*	*HC*	*HCM*	*HC*
Personal Semantic	58	-	16	-	5	-	21	-
General Semantic	60	-	0	-	0	-	40	-
Orientation	50	-	20	-	10	-	20	-
Episodic Past	10	100	0	0	10	0	80	0
Episodic Future	20	93	0	7	30	0	50	0
'DK' Episodic	-	-	22	-	0	-	78	-
'DK' Semantic	-	-	0	-	0	-	100	-

Note: HC = Healthy Controls. All instances of DK / "don't know" represent omissions by HCM except the "Don't know" Episodic and "Don't know" Semantic sections, in which "Don't Know" was the most appropriate response. Incorrect = minor errors.

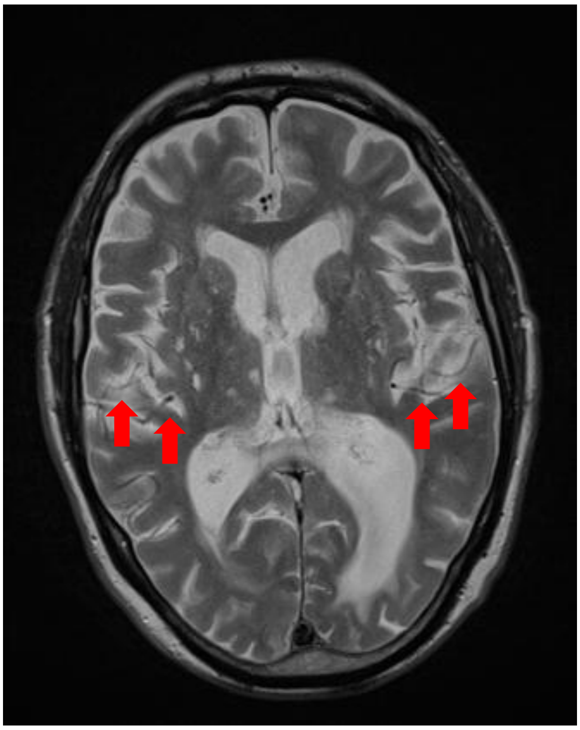

Figure 1. Axial section of patient HCM from a structural MRI scan (produced in 2008). This section illustrates the extent of his enlarged left ventricle, and small vessel change bilaterally (indicated by red arrows). Identification of damage to the hippocampus was unfeasible due to the sections (no coronal view) and the resolution of the above scan.

Appendix

Representative Excerpts from HCM and Healthy Controls (HC) on the Past and Future Episodic Sections of the Confabulation Battery

	Past Episodic			Future Episodic	
Questions	Patient HCM	HC Comparison	Questions	Patient HCM	HC Comparison
Who did you see this morning?	"Can't remember"	"My son and just people in the street" [V, HC1]	*Who are you going to see this evening?*	"Don't know"	"I'm going to see my choir" [personal plaus. = 5, HC2]
What did you do yesterday?	"Can't remember at all"	"We were cooking a lot at my son's house at Bristol: We had my son's girlfriend's parents for a meal" [V, HC2]	*What are you going to do tomorrow?*	"No idea- Talk about what I'm doing here" [personal plaus.=2]	"I've got to do some work on my motorbike. And I will be fiddling about that for about two hours..." [personal plaus. = 5, HC3]
What did you do the day before yesterday?	"Can't remember"	"Nothing much -I just went to Sainsbury's and spoke to my sister on the phone" [V, HC1]	*When will be the next time you visit a friend?*	"Don't know"	"I'll be seeing a friend tomorrow afternoon when I go to the sewing group" [personal plaus. = 4, HC2]
Do you remember the last time you went to see a doctor?	"No"	"Last time I saw my GP would have been 6 weeks ago" [V, HC2]	*When will be the next time you visit a doctor?*	"Don't know"	"audiologist… I might pop in and see him in the next two weeks" [personal plaus. = 5, HC3]
How did you spend last Christmas?	"No idea"	"We went to Austria to do some cross country skiing" [V, HC2]	*When will be the next time you go to a restaurant?*	"When I can afford it -don't know" [personal plaus.=3]	"Probably on Thursday with my sister, we shall probably have a meal out; a lunch or Dinner." [personal plaus. = 5, HC1]

Note: V = verified memory, U = unverified memory (by confederate); Personal plausibility scale ranges from 1-5, 1=implausible, 5=plausibility